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APPLICATION

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TITLE: ANTENNA ARRAY FOR POINT-TO-POINT MICROWAVE RADIO SYSTEM

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ANTENNA ARRAY FOR POINT-TO-POINT MICROWAVE RADIO SYSTEM

TECHNICAL FIELD

[0001] This application relates to point-to-point radio systems, and more particularly to antenna arrays for point-to-point radio systems.

BACKGROUND

[0002] With the increasing use of point-to-point radio systems the efficient use of the allocated transmission spectrum is a growing concern. To improve spectral efficiency, conventional millimeter wave point-to-point radio systems often utilize sophisticated Quadrature Amplitude Modulation (QAM) and error correcting codes to achieve data rates of up to 7 bits per second per hertz of channel bandwidth. For example, one such system that operates at 28 GHz, uses 256 QAM modulation, a symbol rate of 125 M symbols/second, 20% excess bandwidth, and a rate 7/8 convolutional code concatenated with a (188,204) byte Reed Solomon block code to achieve a spectral efficiency of about 5.3758 bits/Hz. Recent improvements in modulation techniques and error correction techniques have led to only marginal improvements in spectral efficiency.

SUMMARY

[0003] A system and method for communicating information between two locations via a wireless microwave link is provided. The system may include at least two antennas, each to transmit information as a narrow beam signal to be directed toward a focal point at a remote location. The antennas may include at least one antenna to transmit a narrow beam signal toward a redirection point different from the focal point. A redirection device located at the redirection point to reflect the narrow beam signal from the at least one antenna element and to redirect the received narrow beam signal toward the receiver. The redirection point is located such that the narrow beam signals from the at least two antenna elements converge and overlap to form an interference pattern proximate to the receiver. The interference pattern includes peaks and nulls that have a peak-to-peak spacing narrower than a width of each of the received narrow beam signals.

[0004] The details of one or more embodiments are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

[0005] FIG. 1 is a top-view block diagram representation of a radio system.

[0006] FIG. 2 is a diagram of an interference pattern formed at a receiving antenna array.

[0007] FIG. 3A is a top-view of an antenna array.

[0008] FIG. 3B is a top-view of an antenna array.

[0009] FIG. 4 is a top-view of an antenna array.

[0010] FIG. 5 is a top-view of an antenna array.

[0011] FIG. 6 is a flow diagram of a method of communicating information between two locations.

[0012] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0013] Figure 1 shows a point-to-point radio system 10 that may be used for communicating information over multiple channels via line of sight communications between building roof-tops. The radio system 10 preferably includes two antenna arrays 12a and 12b for communicating information between two locations. Coupled to each of the antenna arrays 12a and 12b are corresponding radios 14a and 14b. The radio 14a, when performing a transmitting function, generates narrow beam signals that contain the communicated information. The radio

14b when performing a receiving function, receives the signal created from the superposition of the narrow beam signals from radio 14a at the receiving location. The radios 14a and 14b may each include separate radios for generating and receiving the signals. The radio system 10 preferably operates in full duplex mode with each location transmitting and receiving. However, the radio system 10 may also operate in half-duplex mode or be comprised of only one of a transmitting portion and a receiving portion having an antenna array 12.

[0014] Each of the antenna arrays 12a and 12b is comprised of two or more antenna elements 16a-16d with at least one redirection device 18a and 18b configured in relation to a corresponding one of the antenna elements 16a and 16c to redirect signals that are communicated between the corresponding antenna element 16a and the other antenna array 12b or 12a. For example, a signal generated from antenna element 16a of antenna array 12a is directed towards a redirection point at which the redirection device 18a is located. The signal is redirected from the redirection device 18a towards the receiving antenna array 12b. The redirection point is selected so that the redirection device 18a is spaced a separation distance from other redirection devices if any, and/or the antenna elements 16b that point directly at the receiving antenna array 12b. The separation distance is chosen to control the spacing of peaks and nulls in the interference pattern that is created at the receiving location by the superposition of the narrow beam signals emitted from antenna array 12a.

[0015] Figure 2 shows an interference pattern that may be created at the receiving location. The locations of the peaks 20 and nulls 22 are a function of the distance between the antenna arrays 12a and 12b, the size of the transmitting aperture, and the radio carrier wavelength, lambda. The transmitting aperture, which corresponds to the separation distance, x, between the redirection devices 18 and the antenna elements 16b that transmit the narrow beam signals directly towards the receiving antenna array, is adjusted to control the spacings of the peaks and nulls in the interference pattern. The precise location of the peaks 20 and nulls 22 also may be controlled by changing the phasing of the signals generated from the transmitting antenna elements 24 so that, as the phasing is varied, the interference pattern shifts causing the location of the peaks 20 and nulls 22 to shift in relation to the receiving antenna elements 26. In addition, a second set of narrow beam signals may be transmitted from the transmitting antenna elements 24. The phasing of the second set of signals may be controlled so that a peak of the interference pattern associated with the second set of signal falls on one receiving antenna element 26, while a peak of the interference pattern associated with the first set of signals falls on another receiving antenna element 26. Similarly, additional sets of signals may be transmitted in parallel by increasing the quantity of antenna elements 16 and/or redirection devices 18 at the transmitting antenna array 12a and the receiving antenna array 12b. By linear superposition of multiple transmit signals, suitably phase and amplitude controlled, parallel data streams may be transmitted to each receiving antenna separately. The null of one pattern corresponding to a peak (or near peak) of another pattern allows the first signal to not interfere with the second signal. [Good paragraph Chris, MCD]

[0016] If the transmitting antenna elements 24 are placed closer together, then the transmitting array aperture becomes smaller, which in turn widens the main lobe, and the spacing between the nulls and peaks of the interference. The increased separation requirement between the nulls and the peaks of the interference pattern forces the receiving antenna elements 26 need to be widely spaced in order to achieve orthogonality. To attain a symmetric link and maintain orthogonality simultaneously in both directions, the transmitting antenna elements 24 are placed further apart, causing the aperture to increase, the main lobe 20 to narrow, and the distance between the peaks 20 and the nulls 22 to decrease. The spatial repetition frequency of the interference pattern that is created at the receiving antenna elements 26 defines a peak-to-peak spacing that is much narrower than the width of the received narrow beam signals that are generated by the transmitting antenna elements 24. For example, for a 5 kilometer radio link and 38 dBi parabolic dish antennas, the 3 dB beamwidth at the target might be 250 meters across. However, with 28 GHz radio carrier and a transmit array aperture of 10 meters, the peak-to-null spacing would be less than 10 meters.

[0017] Referring to Figure 1, the redirection device 18 may be used advantageously to adjust the transmitting aperture by providing separation between narrow beam signals. Setting the redirection device 18 a separation distance, x, from other redirection devices and antennas 16b that transmit directly towards the other antenna array 12b controls the spacing of the peaks and nulls of the interference pattern created at the receiving antenna array 12b. In addition, spacing apart the redirection device 18b and antenna element 16d of the receiving antenna array 12b in a similar fashion so that the antenna arrays 12a and 12b are symmetrical may provide further advantages such as optimal full-duplex operation and a more efficient use of transmitted signal power. For a radio system 10 that includes multiple transmitting and receiving antenna elements, there is a preferable range for the separation distance, x, between the redirection devices 18a and antenna elements 16b of the transmitter so that one of the interference pattern peaks falls naturally on one receiving antenna while the other receiving antennas lie in nulls. In addition, the redirection devices 18b and antenna elements 16c and 16d of the receiver are preferably spaced apart an interference distance so that, while a peak corresponds to one redirection device or antenna element, nulls correspond to the other redirection devices and antenna elements.

[0018] If "x" is the separation distance, "d" is the distance between antenna arrays, and lambda is the radio carrier wavelength, then the following relationship holds for the preferable separation distance:

$$x \approx \sqrt{\frac{\lambda \cdot d}{2}}$$

[0019] For example, at 28 GHz, the United States Local Multipoint Distribution Service (US LMDS) band, and various antenna array separations, the following table enumerates the optimum separation distances;

Array distance	Separation distance
1 km	2.315 m
3 km	4.009 m
5 km	5.175 m

[0020] At 5.5 GHz, the United States Unlicensed National Information Infrastructure (US UNII) band, and 10 km , the optimum spacing is 16.51 meters.

[0021] For two transmitting antenna elements and two receiving antenna elements, this corresponds to a coupling matrix row of about [1 0]. For a different phasing of the transmitting antennas, the coupling matrix row is about [0 1]. Likewise for a *given* distance d, an appropriate choice of antenna element / redirection element spacing x, and appropriate choices for transmitter signals phases of N transmitting antennas and N receiving antennas, the coupling matrix can approximate a diagonal matrix. Thus, the cross-coupling matrix between the array of transmitters and the array of receivers is approximately a diagonal matrix with small condition number and is readily invertible. For the ideal special case, the cross-coupling matrix is an identity matrix in which the condition number is 1. Therefore, multiple transmitters and receivers may be advantageously operated in parallel resulting in an increase in the number of operational communication channels between the antenna arrays 12a and 12b. Since the communication channels are approximately orthogonal, the data rates of the independent channels may be added to determine the aggregate rate of information flowing between the antenna arrays 12a and 12b. Spacing the transmitting antenna elements apart by the optimal separation distance improves the benefits of spatial processing. Nearly independent parallel radio channels may be produced that can be readily utilized by adaptive spatial processing to dramatically increase data rate without utilizing more radio spectrum. By setting the interference distance approximately equal to the separation distance, x, so that the receiving antenna array is symmetrical to the transmitting antenna array, nearly independent full-duplex parallel radio channels may be established. When the array element spacing is optimized for the wavelength and distance, required transmit power for a given data rate is minimized.

[0022] Although the interference distance is preferably set equal to the separation distance so that a symmetrical link is set up between the antenna arrays 12a and 12b, nearly equivalent interference and separation distances are not required. For example, referring to Figure 2, if the interference distance is not equal to the separation distance, the interference pattern may be controlled to align a null 22 with one receiving antenna element 26 and something less than a peak 20 with another antenna element 26. The received signal has a lower received power level (for a constant transmitted power level) than a signal that is aligned with the peaks 20 and nulls 22. The interference distance also may be set equal to odd multiples of the separation distance, which also results in the peaks 20 and nulls 22 being aligned with the receiving antenna elements 26.

[0023] The antenna elements 16a-16d are preferably directional antenna elements such as parabolic antenna elements. One such example includes a 30 cm parabolic dish with a gain of 38 dBi and beam width of about 1.8 degrees. All other types of directional antenna elements also may be used such as curve-shaped antenna elements. A curve-shaped antenna element may be used in combination with a curve-shaped redirection device 18a-18b to, in combination, provide the effect of a parabolic or near-parabolic shape.

[0024] The redirection device 18 may include devices and objects that may be used to reflect a narrow beam signal. Such devices and objects may include passive reflectors that have flat surfaces, curve-shaped surfaces, and parabolic-shaped surfaces. The redirection device 18 may be a dedicated reflector or an object such as a building that has a reflective surface. In addition, the redirection device 18 may be located in close proximity, for example several meters, to the corresponding antenna element 16b or at a distance such as atop another building. The redirection device 18 may be constructed from flat plate reflectors set at 45 degrees and used in combination with a standard parabolic antenna element 16 that is pointed perpendicular to a point-to-point radio link path extending between the antenna arrays 12a and 12b. Another approach combines curve-shaped elements for both the redirection device 18 and the antenna element 16 that points at the redirection device 18. While curved reflectors are generally more difficult to manufacture than flat plates, the curved elements may provide higher gain, better stiffness, or less weight than flat plates.

[0025] The redirection device 18 preferably includes a reflecting surface composed of a reflecting material for reflecting the narrow beam signals. Suitable reflecting surfaces include metallic surfaces, metallized surfaces, screens, grating patterns, and the like.

[0026] Figure 3A shows an antenna array 30 coupled to a pair of radios 32a and 32b that are mounted back-to-back, thereby minimizing the use of rigid wave-guides between radios.

[0027] In conventional systems, two (or more) transmitting radios are typically spaced apart and interconnected by rigid wave-guides to share local oscillator signals so that the transmitting radios can generate the frequency-coherent, phase offset signals that are required for precise beam and null steering. At very high frequencies such as 28 GHz, running rigid wave-guides between multiple radios that are spaced 7 or 8 meters apart may become difficult and expensive. Similar to the transmitting radios, conventional receiving radios also typically share local oscillator signals with each other to facilitate the modem's proper separation and demodulation of the multi-channel received signals from the transmitting radios.

[0028] Antenna elements 34a and 34b, associated with respective radios 32a and 32b, generate narrow beam signals that are directed towards another antenna array (not shown). At least one antenna element 34a is pointed at a redirection device 36 instead of directly at the other antenna array. The redirection device 36 is spaced apart from the other antenna 34b by the separation distance described above. The narrow beam signal from the antenna element 34a is redirected from the redirection device 36 directly toward the other antenna array. Using one or more redirection devices 18 enables coherent radios to be physically co-located while obtaining a large aperture antenna array. Physical co-location of the radios 32a and 32b facilitates the sharing of high frequency local oscillator signals and simplifies packaging of multi-channel radios. A receiving antenna array (not shown) may be configured similarly, so that the receiving radios may be co-located, thereby minimizing the difficulty of sharing local oscillator signals.

[0029] Figure 3B shows an antenna array 40 that is similar in function to the antenna arrays 10 and 30 except that each of the antennas 44a and 44b in the antenna array 40 direct narrow beam signals towards corresponding redirection devices 46a and 46b.

The redirection devices 46a and 46b are spaced apart from each other the separation distance so that when the antenna array 40 is a transmitting array, the locations of main lobe nulls and peaks fall upon receiving elements of a receiving antenna array (not shown). When the antenna array 40 is a receiving array, the redirection devices 46a and 46b are spaced apart from each other the interference distance so that the locations of main lobe nulls and peaks fall upon the redirection devices 46a and 46b. The redirection devices 46a and 46b may be located at any angle to a link path extending between the antenna array 40 and the other antenna array (not shown) so long as the devices 46a and 46b are spaced apart by approximately the separation distance, x. In addition, two or more redirection devices may be used in series, so that a narrow beam signal that is transmitted from an antenna element is first redirected by one redirection device, then the redirected narrow beam signal is redirected by another redirection device.

[0030] Shown in Figure 4 is another antenna array 50 in accordance with the teachings of the invention. The antenna array 50 is similar in function to the antenna arrays 10, 30, and 40. The antenna array 50 includes six antenna elements 54a-54f for transmitting or receiving signals. Five redirection devices 56a-56e are located at redirection points to redirect signals between corresponding ones of the antenna elements 54 and a receiving antenna array (not shown). To support six independent channels the antenna array 50 includes redirection devices 56a-56e and one of the antenna elements 54f that are spaced apart from each other by the separation distance, x, and by controlling the phasing of the signals that are transmitted from the antenna elements 54a-54f.

[0031] Figure 5 shows a radio system 60 similar in function to the radio system 10 except that the radio system 60 includes radios 62a and 62b that are not in close proximity to each other. For example, the radios 62a and 62b may be separated by several meters or more. The radios 62a and 62b communicate information with receiving radio system (not shown) via narrow beam signals that are transmitted via antenna elements 64a-64d. Each radio 62a and 62b is associated with at least one redirection device 66a and 66b that redirects signals between one of the antenna elements 64a-64d and the other radio system. The two radios 64a and 64b are interconnected via an electrical link 68 such as a rigid wave guide assembly or a wireless assembly to share a common local oscillator signal.

[0032] Figure 6 is a flow diagram of a method of communicating information between a first location and a second location. At state 70, the location of a redirection point is selected so that narrow beam signals transmitted from the first location are spaced apart from each other by a predetermined separation distance. The separation distance is selected so that an interference pattern having main lobe peaks and nulls is formed in the vicinity of the second location, in which the spacing of the peaks is narrower than the received narrow beam signals. At state 72, narrow beam signals for communicating information between the two locations are generated. The narrow beam signals are transmitted from the first location to be directed toward an antenna array at the second location. At state 74, one or more of the narrow beam signals is directed at a corresponding redirection point. The narrow beam signals directed at redirection points are redirected towards the second location antenna array. At state 76, the interference pattern may be controlled by methods such as spatial processing so that the location of a peak is aligned with one receiving element at the second location, and nulls are aligned with other receiving elements at the second location. The interference pattern may alternatively be controlled to align nulls with all but one of the receiving elements. The remaining receiving element is then aligned with a portion of the interference pattern other than a null allowing information to be carried from the transmitting array to this antenna. Continuing to state 78, the phasing of the transmitted narrow beam signals is varied so that the location of the peaks and nulls is precisely controlled.

[0033] Other embodiments are within the scope of the following claims.